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Upgrade options for Femtosource

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Introduction

This time we want to fix the top beam energy for Berkeley Femtosource. It will allow us to finally settle with the machine lattice and to move into freezing of other machine parameters. Present lattice design allows 4 GeV (3.9 GeV actual operation energy since we may need extra margin for a magnetization loop). Present linac design allows 2.5 GeV. The decision about energy upgrade for the linac can be deferred, if it is permitted by lattice.

Undulator radiation

Here we present the background information needed for the decision making. We consider three beam energies: 2.5 GeV, 3.1 GeV and 3.8 GeV. For each energy we consider four types of undulators of increased technical difficulty. The assumed basic design for undulators is a superconducting in-vacuum undulator similar to Moser-Rosmanith's undulator. In all four cases the length of the undulator is 2 m, which is restricted by present lattice design. The main undulator characteristics are listed in the Table 1.

Table 1. Main undulator characteristics.

Type	Period, mm	Gap, mm	Peak magnetic field, T	Undulator parameter, K
1	20	5	1.5	2.8
2	14	5	1.5	2.0
3	14	3	2.0	2.6
4	10	3	1.5	1.4

) Types 2 and 3 can be covered with one undulator with the adjustable gap.

For all energy and undulator type cases we show results of the calculation of the x-ray flux (number of x-ray per second and per 0.1% bandwidth) as a function of the photon energy. Notice, that plots give flux for odd undulator harmonics from the first to the eleven harmonics. Each curve was created by changing the undulator magnetic field until it reached the maximum field. If correspondent neighboring curves do not interleave, then it means that it is not possible for a given maximum undulator field. We cut plots at a flux level of 10^{10} photons per 0.1%bw. For an electron beam we assume 10 kHz repetition rate and 1 nC per bunch. The normalized electron beam emittance is 20 mm-mrad in the horizontal plane and 0.4 mm-mrad in the vertical plane. The absolute energy spread is 150 keV. We also assumed 50m vertical beta-function in the deflecting RF structure and 2.5m and 7.5m vertical and horizontal beta-functions in the undulator. Using these parameters we calculate a compression of the x-ray pulse and plot FWHM of the x-ray pulse in fs for each beam energy.

For reader convenience Table 2 summarizes the findings showing flux numbers for three photon energies: 2 keV, 6 keV and 10 keV. When one of these photon energies appears in between two numbers reachable by neighboring undulator harmonics, than we give the nearest photon energy instead of the flux number.

Table 2. Flux of the undulator radiation given at 2 keV, 6 keV and 10 keV photon energy for three electron beam energies and four types of the undulator of increased technical difficulty.

Undulator	x-ray,keV	2.5	3.1	3.8
type	keV	GeV	GeV	GeV
	2	8	11.4	12.8
1	6	2.4	4.4	6.7
	10	1.1	2.7	4.2
	2	15.6	17.8	(3.3 keV)
2	6	5.5	(5 keV)	12.4
	10	2.3	4.5	8.6
	2	15.6	17.8	19
3	6	5.5	9	12.4
	10	2.3	4.5	(11 keV)
	2	(2.6 keV)	(3.5 keV)	(7 keV)
4	6	(5 keV)	15.8	13.1
	10	5	(8 keV)	(12 keV)

à Beam energy 2.5 GeV

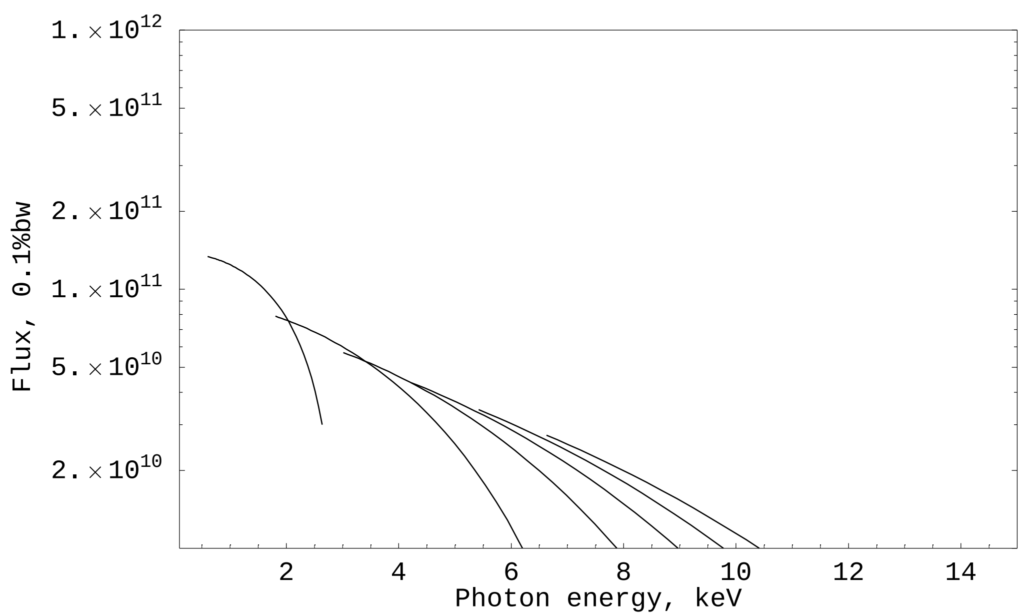

Figure 1. Kmax=2.8, period=2.0 cm (Gap=5 mm, Bpeak=1.5 T)

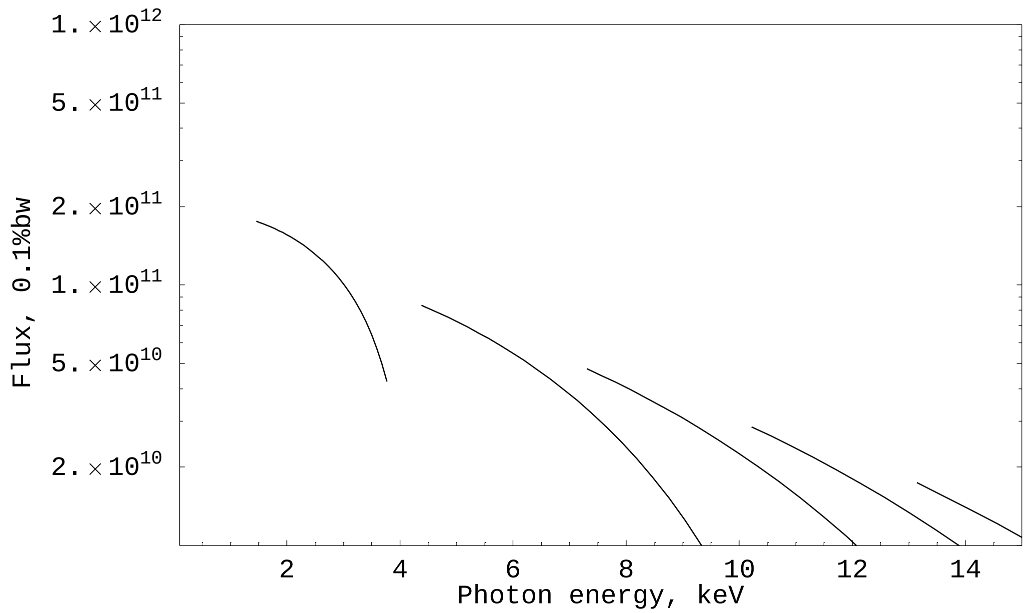

Figure 2. Kmax=2, period=1.4 cm (Gap=5 mm, Bpeak=1.5 T)

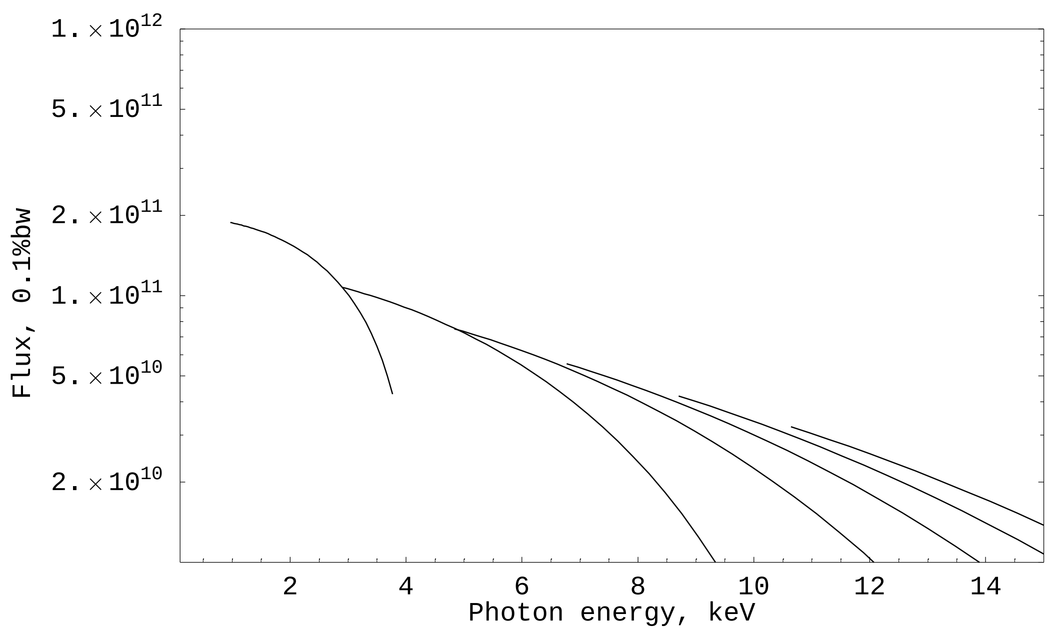

Figure 3. Kmax=2.6, period=1.4 cm (Gap=3 mm, Bpeak=2 T)

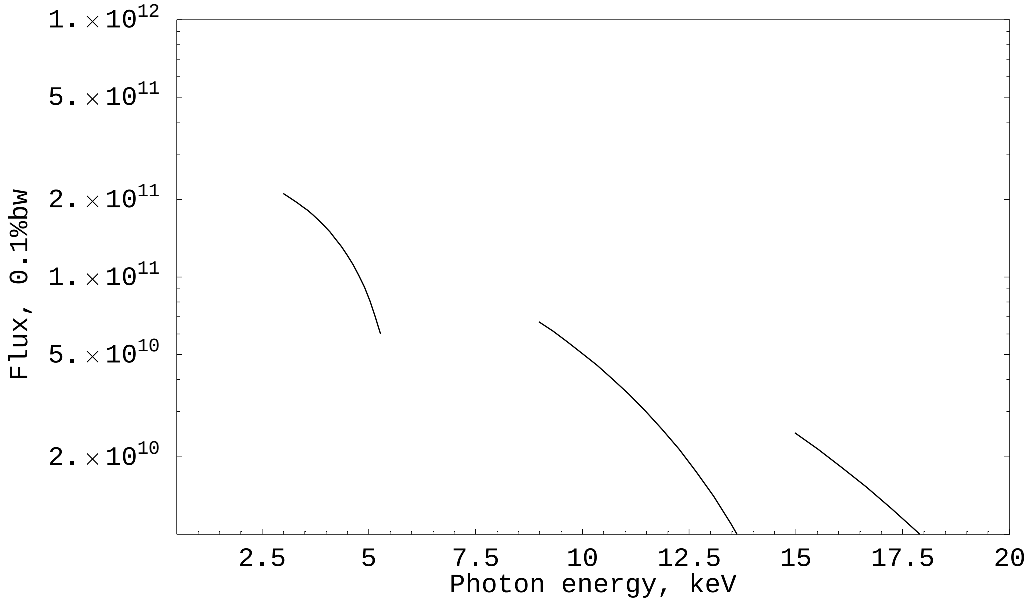

Figure 4. Kmax=1.4, period=1.0 cm (Gap=3 mm, Bpeak=1.5 T)

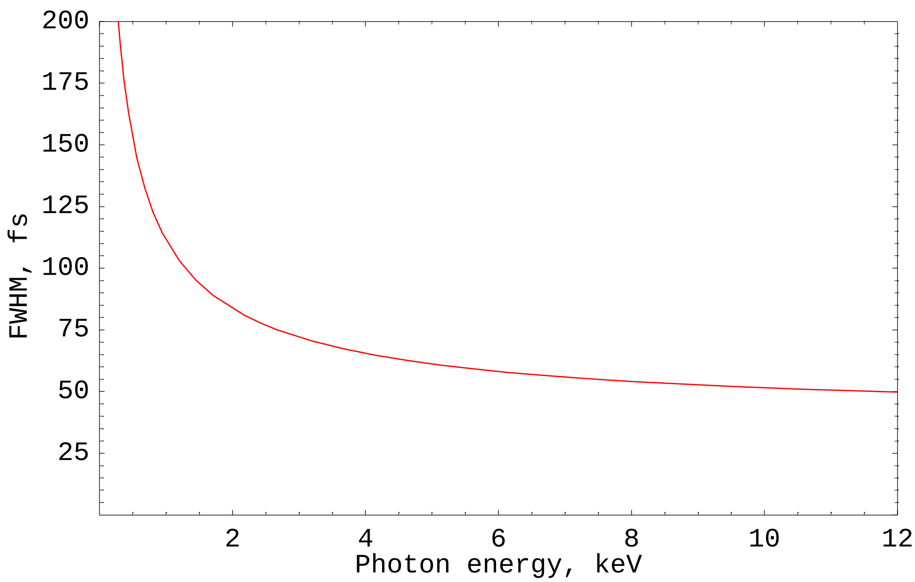

Figure 5. Beta_rf = 50m, Urf=7.4 MV, tilt angle = 160 microrad

à **Beam energy 3.1 GeV**

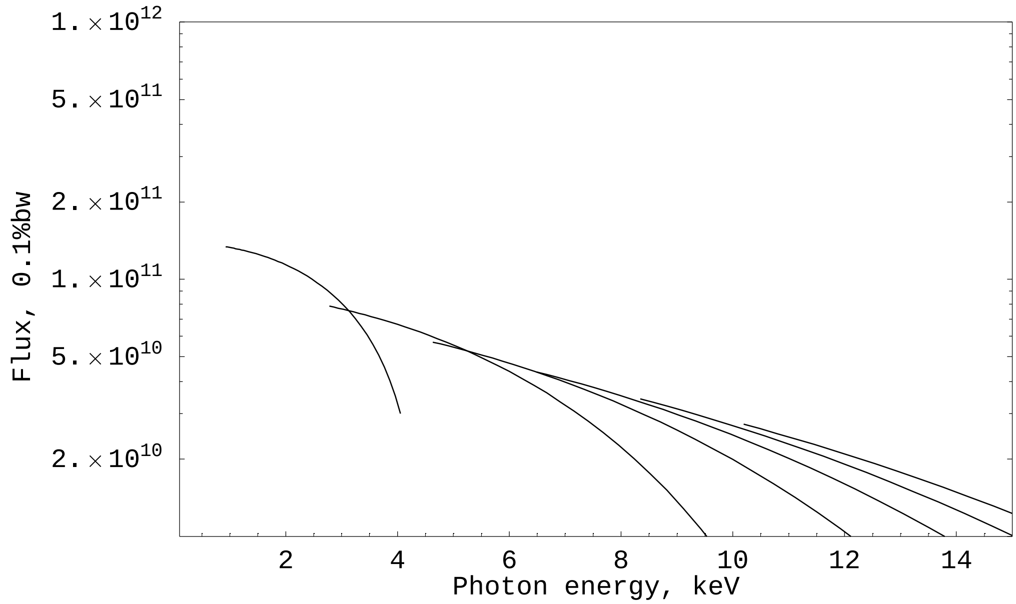

Figure 6. Kmax=2.8, period=2.0 cm (Gap=5 mm, Bpeak=1.5 T); (compare with Figure 1)

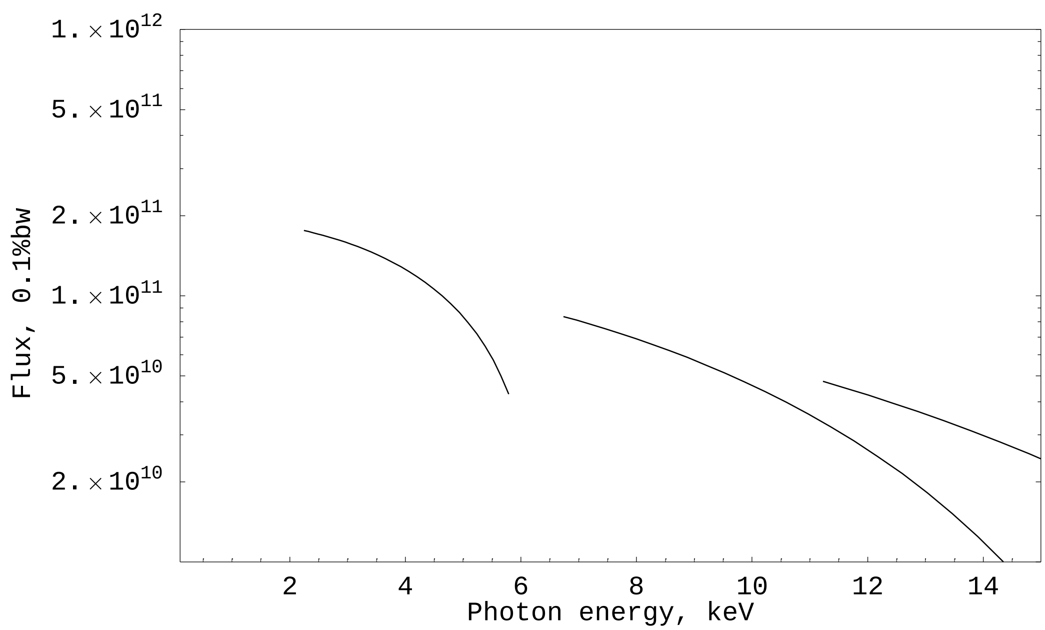

Figure 7. Kmax=2, period=1.4 cm (Gap=5 mm, Bpeak=1.5 T); (compare with Figure 2)

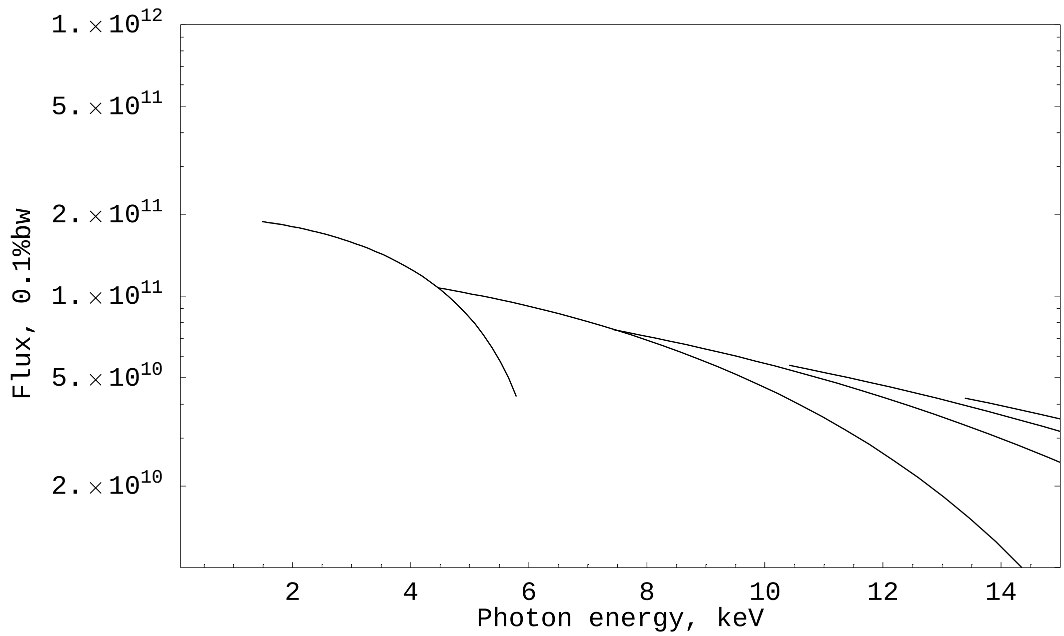

Figure 8. Kmax=2.6, period=1.4 cm (Gap=3 mm, Bpeak=2 T); (compare with Figure 3)

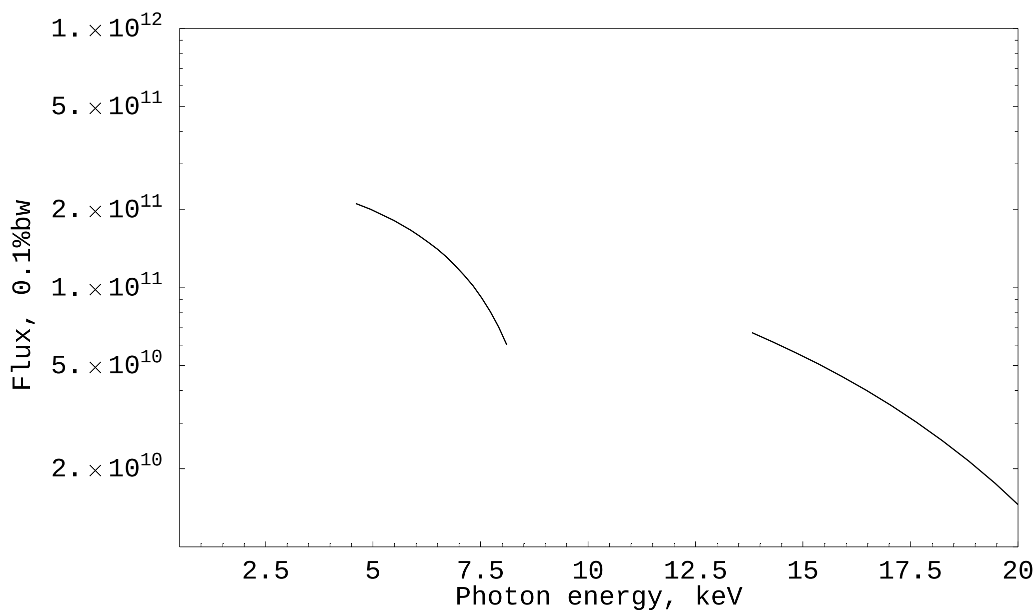

Figure9. Kmax=1.4, period=1.0 cm (Gap=3 mm, Bpeak=1.5 T); (compare with Figure 4)

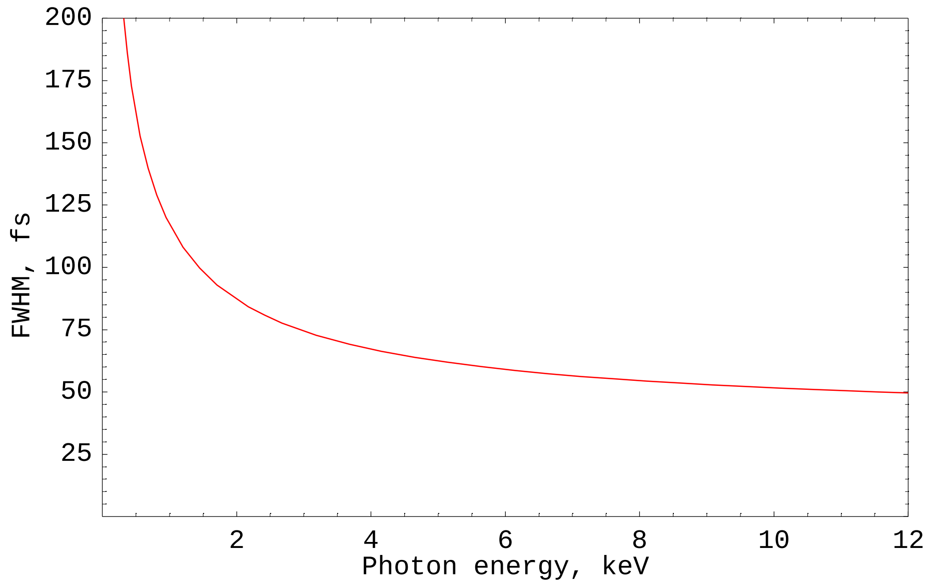

Figure 10. Beta_rf = 50m, Urf=8.5 MV, tilt angle = 150 microrad

à Beam energy 3.8 GeV

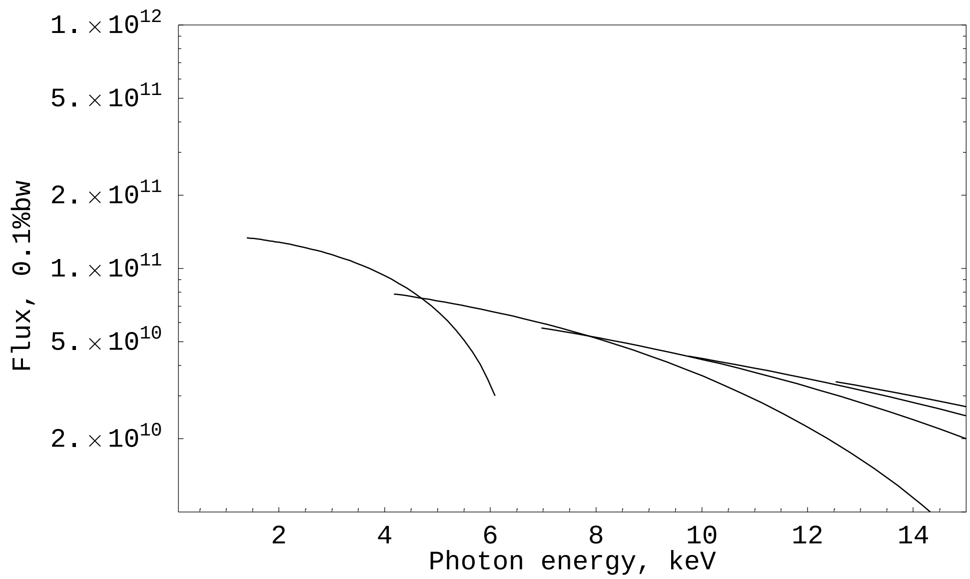

Figure 11. Kmax=2.8, period=2.0 cm (Gap=5 mm, Bpeak=1.5 T); (compare with Figure 1 and 5)

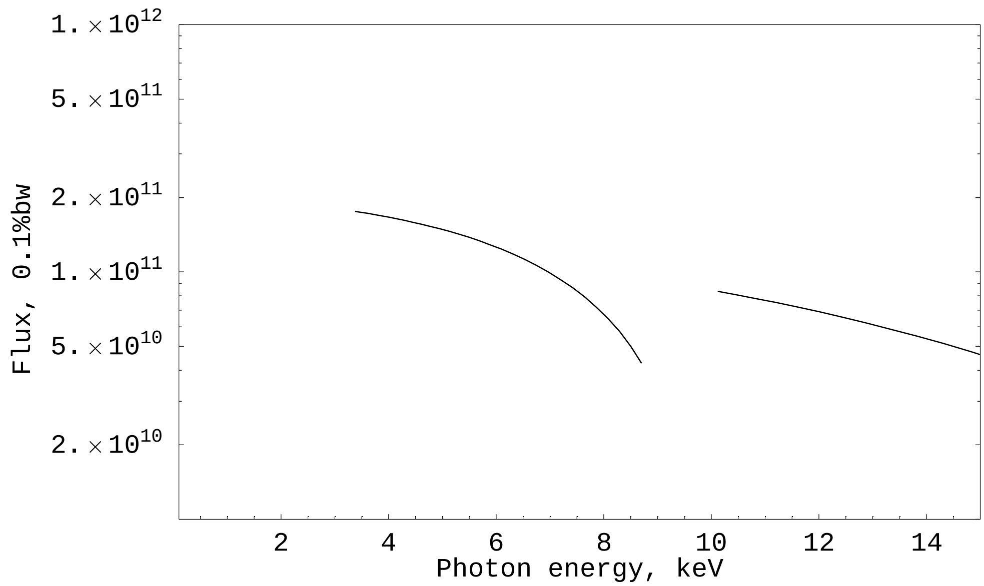

Figure 12. Kmax=2, period=1.4 cm (Gap=5 mm, Bpeak=1.5 T); (compare with Figure 2 and 6)

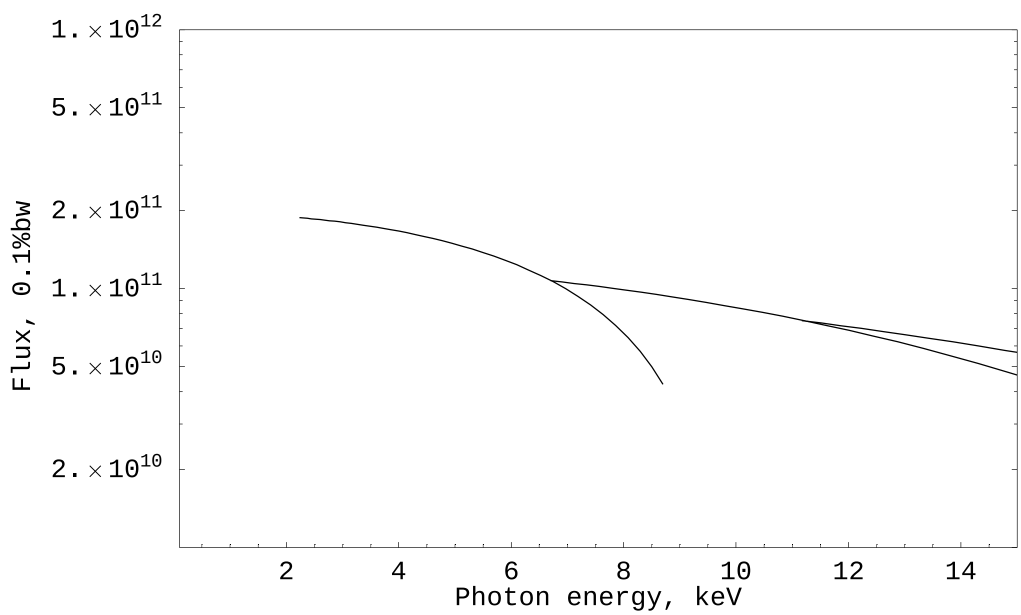

Figure 8. Kmax=2.6, period=1.4 cm (Gap=3 mm, Bpeak=2 T); (compare with Figure 3 and 8)

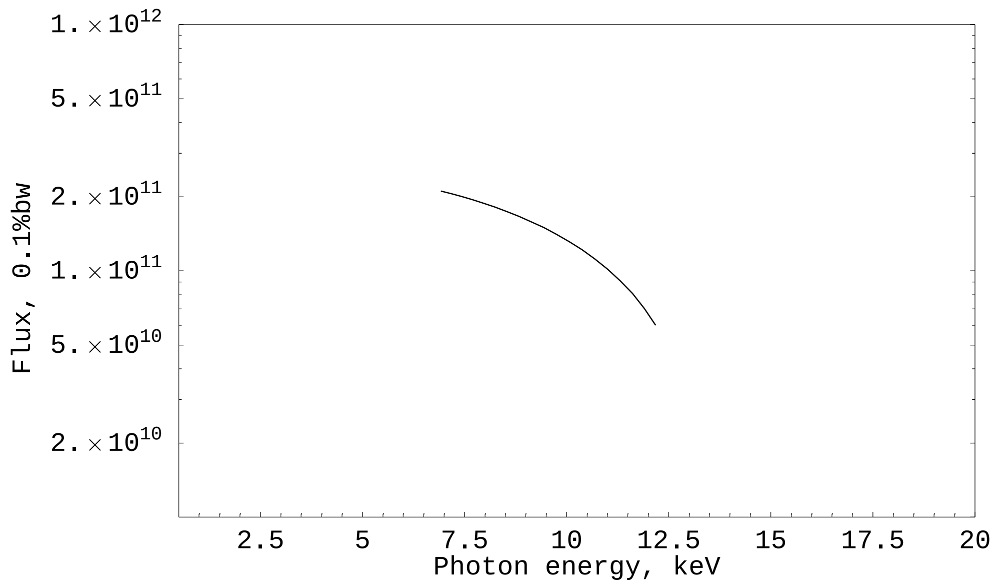

Figure9. Kmax=1.4, period=1.0 cm (Gap=3 mm, Bpeak=1.5 T); (compare with Figure 4 and 8)

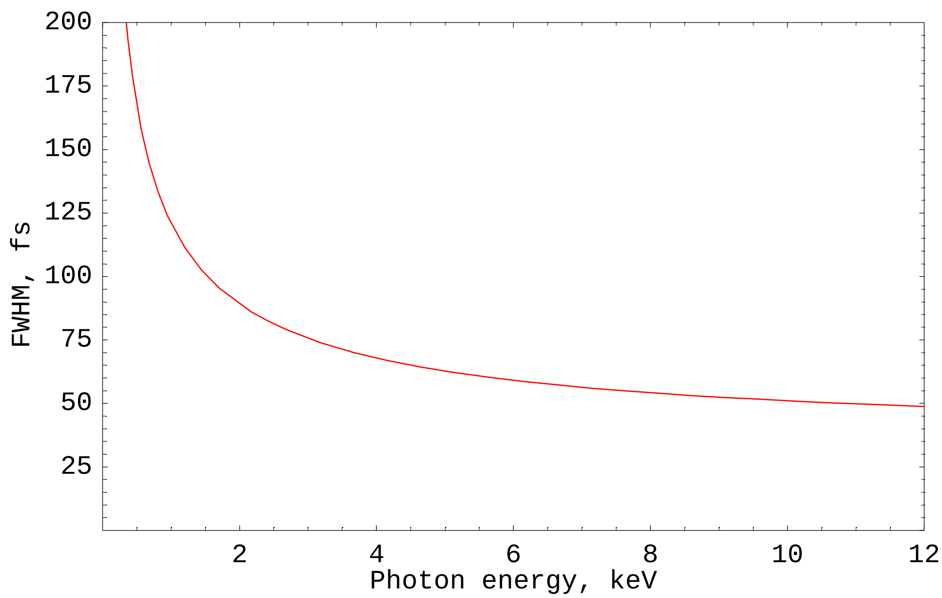

Figure 15. Beta_rf = 50m, Urf=10 MV, tilt angle = 140 microrad

Bend magnet radiation

In the present design we assume bend magnet with 2 T field at 2.5 GeV. However, the bend magnet provides a turn in the electron beam trajectory and a stronger magnet will be needed for the increased electron beam energy, basically, a superconducting magnet. Other approach is to assume that we will use 2 T magnet at the top electron beam energy (whatever it will be) and will operate with a weaker magnet at lower energies. In this note we favor the second approach. We show three plots of the x-ray flux demonstrating what we can get if our top energy choice will be either 2.5 GeV, 3.1 GeV or 3.8 GeV.

1. The top energy is 2.5 GeV and the bending field at the top energy is 2 T.

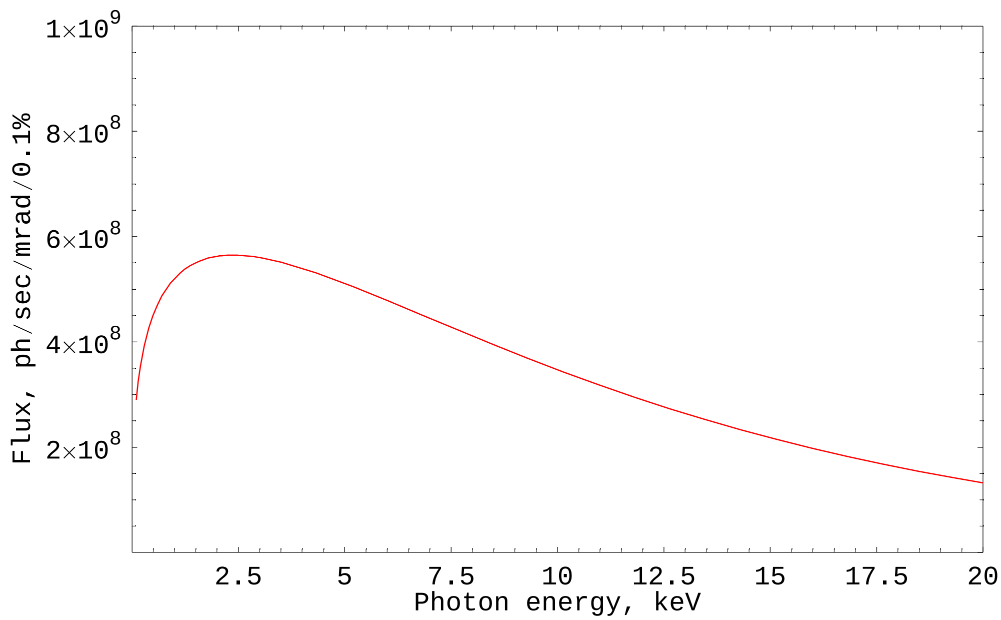

Figure 16. X-ray flux of the bend magnet radiation. Magnetic field is 2 T, beam energy is 2.5 GeV.

2. The top energy is 3.1GeV and the bending field at the top energy is 2 T.

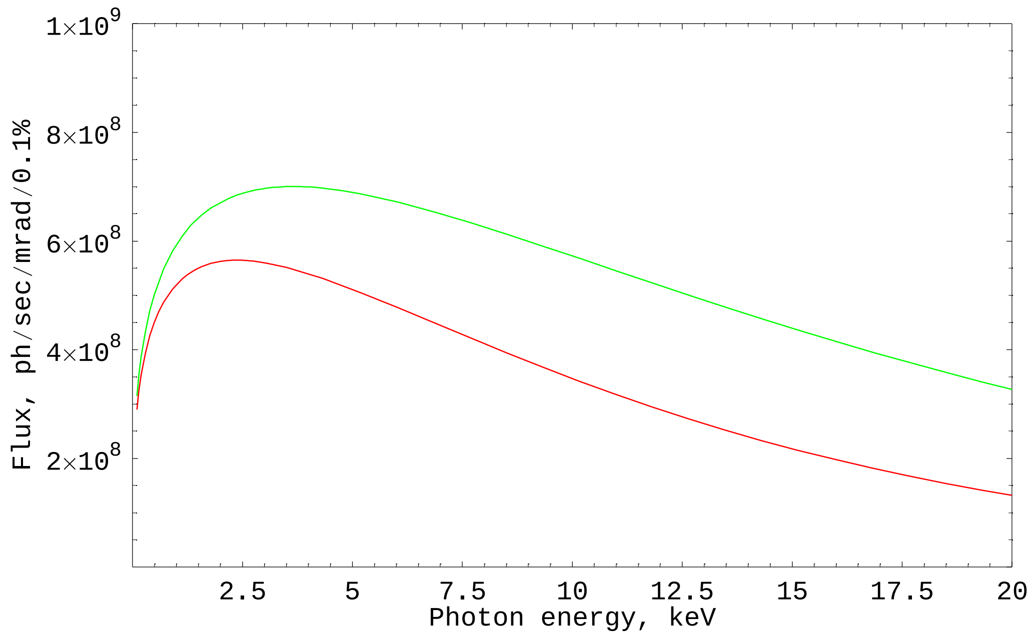

Figure 17. X-ray flux of the bend magnet radiation. Green curve: magnetic field is 2 T, beam energy is 3.1 GeV. Red curve: magnetic field is 1.61 T, beam energy is 2.5 GeV.

3. The top energy is 3.8 GeV and the bending field at the top energy is 2 T.

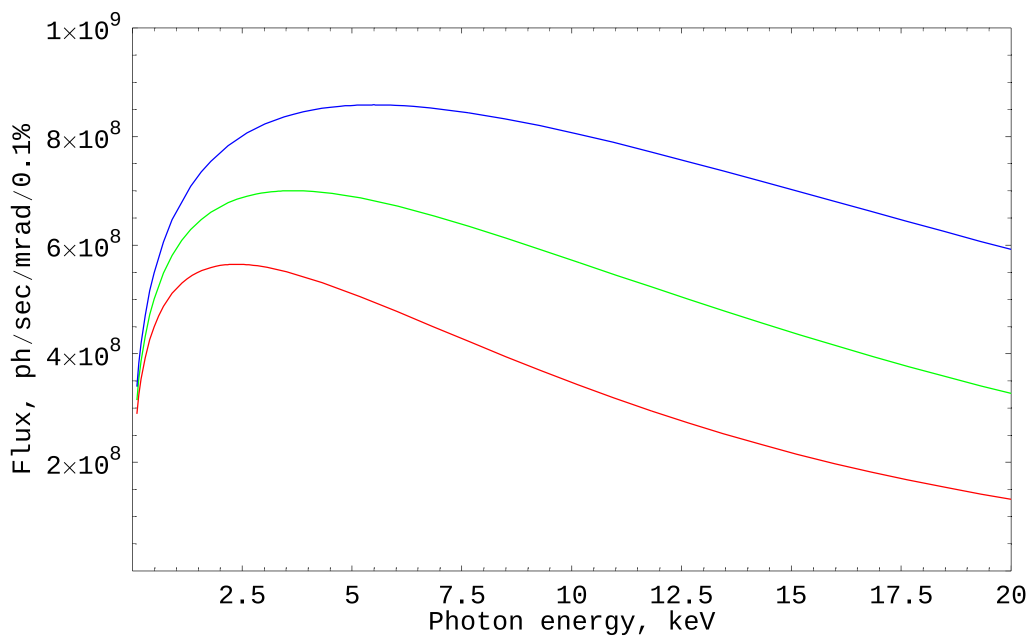

Figure 18. X-ray flux of the bend magnet radiation. Blue curve: magnetic field is 2 T, beam energy is 3.8 GeV. Green curve: magnetic field is 1.63 T, beam energy is 3.1 GeV. Red curve: magnetic field is 1.32 T, beam energy is 2.5 GeV.

Using the 1.7 m vertical beta-function in the bending magnet we calculate a compression of the x-ray pulse and plot FWHM of the x-ray pulse in fs for 2.5 GeV beam energy. Other beam energies will have similar plots.

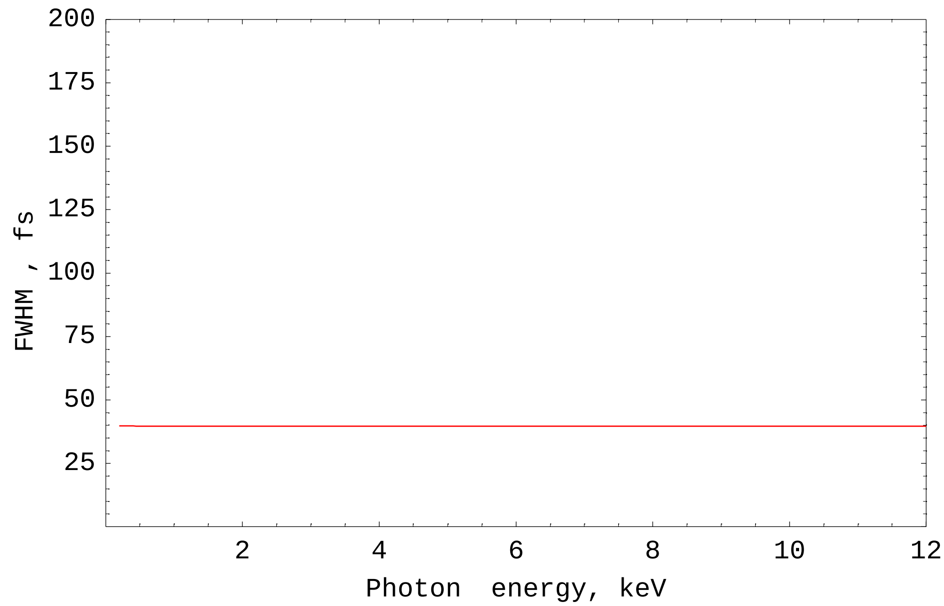

Figure 19. Beta_rf = 50m, Urf=7.4 MV. This plot shows that the x-ray pulse duration is dominated by the actual source size due to the e-beam emittance and the x-ray diffraction has a negligible effect even at a low photon energies.